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ORIGINAL PAPER

Floods in Provence-Alpes-Côte d'Azur and lessons for French flood risk governance

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Abstract

France experiences catastrophic floods on a yearly basis, with significant societal impacts. In this study, we use multiple sources (insurance datasets, scientific articles, satellite data, and grey literature) to (1) analyze modern flood disasters in the PACA Region; (2) discuss the efficiency of French public policy instruments; (3) perform a SWOT analysis of French flood risk governance (FRG); and (4) suggest improvements to the FRG framework. Despite persistent government efforts, the impacts of flood events in the region have not lessened over time. Identical losses in the same locations are observed after repeated catastrophic events. Relative exposure to flooding has increased in France, apparently due to intense urbanization of flood-prone land. We suggest that the French FRG could benefit from the following improvements: (1) regular updates of risk prevention plans and tools; (2) the adoption of a build back better logic; (3) taking undeclared damages into account in flood risk models; (4) better communication between the actors at the different steps of each cycle (preparation, control, organization, etc.); (5) better communication between those responsible for risk prevention, emergency management, and disaster recovery; (6) an approach that extends the risk analysis outside the borders of the drainage basin; and (7) increased participation in FRG from local populations.

Keywords France · Natural hazards · Disaster risk reduction · Flood risk governance · Resilience · Public policy

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1 Introduction

Flooding is widely considered to exert the greatest societal impacts of all natural hazards (CRED-UNISDR 2015). The total amount of damage resulting from flood disasters globally is expected to rise in the future, due to long-term impacts of climate change, including the rise in sea level (e.g., Hallegatte et al. 2013), intensification of precipitation events (e.g., Lenderink and Van Meijgaard 2008; Coumou and Rahmstorf 2012), and socio-economic factors (e.g., Vedeld et al. 2016; Winsemius et al. 2016; Luke et al. 2018), such as expansion of urbanization (e.g., Swiss Re 2014; Miller and Hutchins 2017; Zhang et al. 2018; Koc and Işık 2020). Furthermore, flood losses have increased globally (e.g., Bouwer 2011; Surminski et al. 2015; Cremades et al. 2018) and now represent the largest proportion of insured losses among catastrophes induced by natural hazards; global costs were approximately €50 billion in 2016 alone (Aerts et al. 2018).

Since the start of the twenty-first century, numerous researchers (e.g., Hall et al. 2005; Lumbroso et al. 2011; Alexander et al. 2015; Mees et al. 2016) and international organizations (e.g., UNISDR, Sendai Framework 2015) have attempted to address these issues nationally or globally by focusing on improving flood risk governance (FRG), which, according to Ishiwatari (2019), determines how flood risk is managed and how the costs and benefits of flood management are distributed within society. Furthermore, Dixit (2003) suggests that the vulnerability of people in risk-prone areas must be addressed by enhancing resilience, which is defined as the ability of a system, community, or society exposed to hazards to resist, absorb, accommodate to, and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions (UNISDR 2009). Lamond et al. (2019) discuss desirable improvements for several sectors (e.g., access to adequate risk information, professional skills in evaluating risk, guidance on evaluation of flood risk), to ensure sufficient consideration of risk and mitigation options. Even though impacts from flooding are disproportionately high for the poorest and most vulnerable (e.g., Jongman 2018), studies show that the developed world is also under threat (Kaufmann and Wiering 2017; Hudson et al. 2019; Miller and Hutchins 2017; Crichton 2008). For example, Paprotny et al. (2018) indicate that the total urban area exposed to flooding in Europe has increased by 1,000% over the past 150 years.

France is one such European country that faces catastrophic flood events on an annual basis (Boudou et al. 2016; Larrue et al. 2016). The NatCatSERVICE (2017), which is provided by Munich Re to the European Environment Agency under institutional agreement, and which illustrates the impacts of extreme weather and climate-related events in the European Economic Area (EEA) member countries (1980–2017), ranks France as having had the most flood-related fatalities (from extreme weather and climate-related events) in Europe (approximately 23,500 over the period 1980–2017), and having had the third-greatest total economic losses (behind Germany and Italy) and insured losses (behind Germany and the UK) related to flooding. Furthermore, according to Paprotny et al. (2018), while overall exposure to floods has declined in most European countries, notably in central and northern Europe, relative exposure has increased in France and other western states (i.e., Germany, the Netherlands), apparently because of intense urbanization processes, occupying and transforming flood-prone land. A potential 2 °C increase in global temperatures would likely exacerbate this problem by significantly increasing the probability (Roudier et al. 2016) and severity of flooding. These events could vary from tidal floods and storm surges in the west and north of France, to flash floods in the south and fluvial floods along

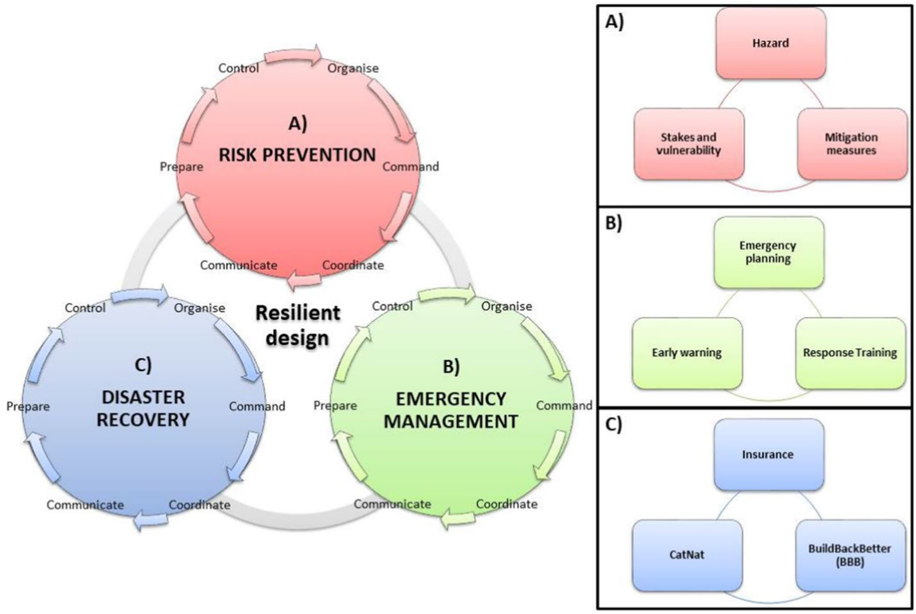

Fig. 1 French flood risk governance (FRG) system

main rivers, as well as urban flooding in many cities (Larrue et al. 2016). Previous studies have focused on different phases and components of French flood risk governance (FRG), including flood hazard (e.g., Boudou et al. 2016; Montané et al. 2017; Evin et al. 2019); flood risk (e.g., Le Coz et al. 2016; Liefferink et al. 2018; Creach et al. 2020); the role of the government as a predominant actor in the FRG system (Larrue et al. 2016; Fournier et al. 2018; Fournier 2020; and the Natural Disaster Compensation Scheme (CatNat) (e.g., Magnan 1995; Scolobig et al. 2014; Guillier 2017), which was created in 1982 to manage damage compensation for extreme natural disasters based on an insurance super-fund (Barraqué and Moatty 2020).

Each of these studies is valuable for its treatment of different phases of French FRG. However, few studies focus on the system as a whole to show the links, if any, between different phases of the governance cycle. Studies attempting to analyze national governance frameworks for different natural hazards have been developed for different countries, such as Thailand and the USA (e.g., Singkran and Kandasamy 2016; Tullos et al. 2016). These papers usually summarize the governance framework studied and suggest any appropriate changes, based on the analysis of laws, policy documents, or empirical data. Another example is the International Risk Governance Center (IRGC) framework (2020), a governance tool that involves all stakeholders that could be affected by a risky activity or event, and specifies the management options taken to counter the risk. In Fig. 1, we identify the main phases of the integrated flood governance approach in France as described by Larrue et al. (2016) and the French Ministry of Ecological Transition (Ministère de la transition écologique) (2020).

Each main phase of the cycle (risk prevention, emergency management, and disaster recovery) contains multiple components (e.g., hazard, early warning, CatNat) that are considered simultaneously when analyzing the framework. Specifically, risk prevention involves analysis of the hazard (i.e., a flood, or knock-on effects, such as landslides), the vulnerability of local stakeholders (e.g., building material, age distribution, access to health services), and mitigation measures to be used to prevent a disaster (e.g., dikes, retention ponds). Emergency management comprises planning with scenario-making from local government services, response training of concerned teams (e.g., fire brigade, ambulance), and early warning systems (e.g., flood depth alerts). Disaster recovery is characterized by three criteria. The first is related to the public solidarity system, CatNat, which is triggered once municipalities claim that they have been affected by an exceptional event and the State acknowledges the claim. The second relates to private insurance companies, which provide additional coverage for elements not covered by the CatNat system. We can identify a third criterion that has appeared more recently and relates to the build back better (BBB) culture, which was first officially used in the Sendai Framework (UNISDR 2015) and focuses on improving land use, spatial planning, and construction standards through the recovery process (Noy et al. 2019). Each of these phases contains a series of steps (e.g., preparation, control, communication) that guarantee the appropriate operation of the FRG cycle.

Despite the resilient design of current French FRG, several deficiencies are observed when a flood disaster occurs. To assess the efficiency of the French FRG system, we focus on the Provence-Alpes-Côte d'Azur (PACA) region in France for two reasons: (1) the region has suffered repeated flood disasters for approximately 30 years despite government prevention efforts; and (2) the incidence of flood disasters has increased in recent years, making an assessment of the effectiveness of public policy timely. For our analysis, we use multiple data sources (insurance datasets, scientific articles, satellite data, grey literature) with a fourfold purpose: (1) to analyze modern flood disasters in the PACA region; (2) to discuss the efficiency of French public policy instruments; (3) to perform a strengths, weaknesses, opportunities, threats (SWOT) analysis of French FRG; and (4) to suggest improvements.

2 Extreme flooding in Provence-Alpes-Côte D'Azur (PACA)

2.1 Study area and past flood disasters

The PACA region in France is characterized by steep slopes and deep valleys; the coastal plains are enclosed by the Cévennes mountain range to the northwest and the Alps to the east. Summer drought and intense autumn rainfall are typical features of the climate (Petrucci et al. 2019). Rainfall is concentrated over the period September–December (50% of annual total). Winter is drier with cold, continental winds. Flash floods are common in the region (e.g., Vinet 2008a, b; Vinet et al. 2012; Heinzlef et al. 2019), with a significant number of fatal historical events taking place since the creation of the CatNat national solidarity scheme in 1982. Some notable extreme flooding events that have provoked loss of life, as well as significant material costs, include the Vaison-la-Romaine floods (September 1992), the Draguignan floods (June 2010), and the most recent Côte d'Azur floods (October 2015). The region has also faced smaller flood events, such as the Var and Alpes-Maritimes floods (November 2011, November–December 2019) and the Nice floods (November 1994, December 2005). In Fig. 2, we provide a map of the study area (PACA region) and of the most notable flood events.

In the last 10 years, several PACA municipalities have attempted to emphasize resilience in their urban planning in response to repeated flooding (Heinzlef et al. 2019). For

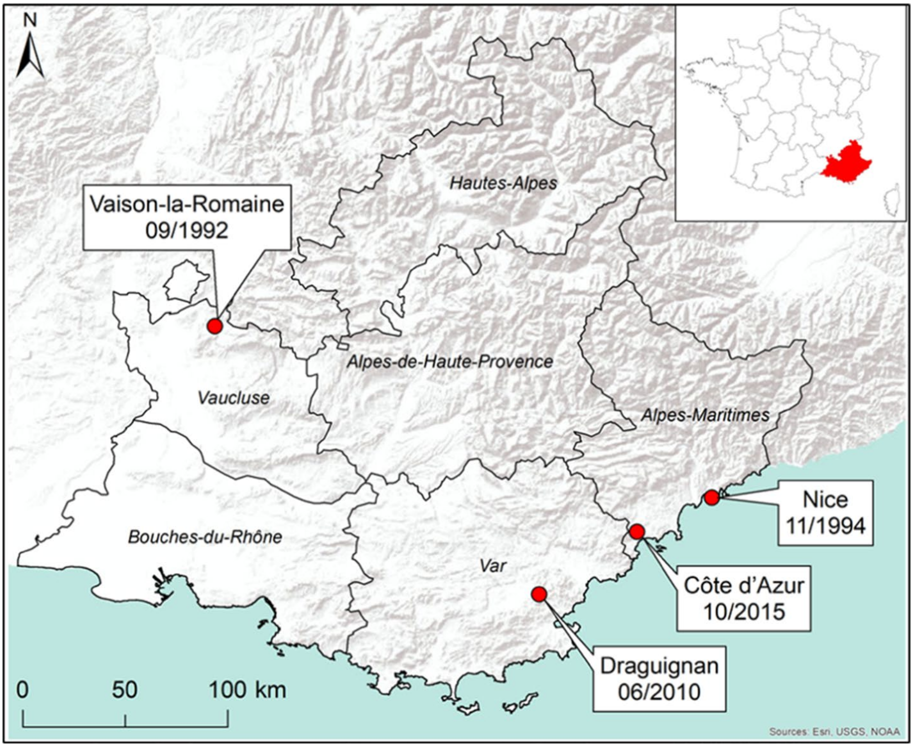

Fig. 2 Map of major flood events in PACA

example, Avignon is applying a holistic methodology for resilience to floods with social (e.g., education, insurance), technical (e.g., engineering, transport network), and urban (e.g., economical dynamics, environment) characteristics. The city already uses these new results and mapping to build an urban well-being indicator.

2.2 The October 2015 Côte d'Azur disaster

According to the official post-event report of the Préfet (regional authority) des Alpes-Maritimes (2016), on Saturday, October 3, 2015, between 20:00 and 21:45, an exceptional rainfall event took place between Mandelieu-la-Napoule and Nice (for official rainfall maps see Météo-France[1]). The report also suggests that this event delivered approximately 200 mm of precipitation in two hours and is comparable to a catastrophic event that took place in the same region in 1966. According to Carrega (2016), these values correspond to a larger than 100-year storm. More specifically, the Cannes meteorological station recorded 175 mm of rainfall in two hours, which is approximately 80 mm more than the 100-year event (94.6 mm). This exceptional rainfall caused a substantial increase in surface run-off and subsequent river discharge (> 250 m^3/s, again, larger than the 100-year event), in the Argentière and Brague rivers. In addition, due to the region's steep slopes, which are

[1] http://pluiesextremes.meteo.fr/france-metropole/Catastrophe-sur-la-Cote-d-Azur.html.

covered by Mediterranean vegetation, large pieces of woody debris were swept into water courses, damming the main channels and causing water to be diverted onto floodplains. The Préfet's report (2016) declared that 20 people lost their life during the event and that 1,200 people were in need of immediate disaster relief measures.

2.3 Identifying flood risk governance deficiencies after the disaster

In the years, following the October 2015 disaster, several reports were published (e.g., that of the Préfet des Alpes-Maritimes 2016; ARTELIA 2017; CEREMA 2019) listing a number of pre-existing issues that could have led to the disaster. They included inadequate land-use planning, inadequate prevention plans, inadequate warning systems, inadequate maximum threshold for emergency calls (only 20 simultaneously), the lack of appropriate rain forecast modelling, citizens' ignorance of what to do after an alert is initiated (lack of operational knowledge), and the lack of road network mapping. These issues seem to be the same as the those in past local disasters (listed in Sect. 2.1). In Sects. 2.3.1–2.3.3, we will briefly analyze all aspects of the FRG framework in PACA (as summarized in Fig. 1) to observe, in detail, the pitfalls leading to repeated disasters.

2.3.1 Risk prevention

The current French FRG system is based on prevention and the main goal is to reduce exposure to risk through the use of legal instruments (e.g., Kaufmann and Wiering 2017; Fournier et al. 2018). There are two main instruments: (1) the Plans de Prévention du Risque d'inondation (PPRi), which offer maps identifying areas exposed to a reference flood hazard (often the 100-year event) and include bans or restrictions on construction, depending on an area's risk level (Barraqué and Moatty 2020); (2) the Programme d'Action pour la Prévention des Inondations (PAPI), which has several aims, including creating synergy and coordinating actions and actors at the prevention level and river basin scale, and developing a multi-year strategy that relies on the implementation of other existing public policy tools (Guillier 2017). According to Dubert et al. (2016), the most exposed municipalities with the most elevated mortality rates did have a PPRi at the time of the October 2015 event. This is further evidenced by the insurance datasets that were provided to us, from experts of the Caisse Centrale de Réassurance (CCR), the Directions Régionales de l'Environnement, de l'Aménagement et du Logement (DREAL), and the Centre d'études et d'expertise sur les risques, l'environnement, la mobilité et l'aménagement (CEREMA), after four meetings (April 2019, July 2019, October 2019, and December 2019). The insurance datasets these organizations provided illustrated that all municipalities that recorded fatalities (e.g., Mandelieu-La-Napoule—10 deaths, Vallauris—three deaths, Cannes—two deaths) had a PPRi. Furthermore, it seems that these instruments were significantly out of date when the disaster happened (e.g., in Cannes the last PPRi was approved in 2003).

After earlier disasters that occurred at the turn of the millennium (e.g., 1999 in the Aude department, 2002 in the Gard department—see Vinet 2008b), the idea that flooding is a controllable natural phenomenon was challenged and a focus on analysis of vulnerability was suggested (Vinet 2004, 2007, 2008a). Also, the effectiveness of structural measures began to be questioned (Kaufmann and Wiering 2017; Kron et al. 2019). During the October 2015 Côte d'Azur disaster, the artificial protection dikes were largely ineffective due to the severity of the phenomenon (with river discharges larger than the 100-year event), while some dikes trapped large debris, blocking the flow and worsening the situation

(Préfet des Alpes-Maritimes report 2016). A similar phenomenon was observed in the September 1992 Vaison-la-Romaine disaster. According to Ballais and Segura (1995), the protection dikes and embankments that were installed along the River Ouvèze during World War II, to straighten the channel in the valley and provide space for construction, intensified runoff turbulence, and transported boulders and woody debris that blocked bridges and promoted damage downstream.

After the October 2015 event, PACA inhabitants were promised the construction of new retention ponds as well as the reinforcement of mitigation measures (ARTELIA 2017). Flood mitigation measures such as retention ponds and wetland restoration are considered a viable option for flood management because they improve runoff management while legitimating the PAPI project, illustrating the advantages of land-based flood control (Barraqué and Moatty 2020). In 2001, some years after the Vaison-la-Romaine and other flood disasters around France, the Assemblée Nationale (2001) published a document suggesting measures for regions facing repeated flood disasters, like the PACA region. It observed that natural retention capacity has decreased due to the disappearance of wetlands, which were often replaced by intensive agriculture, heavy infrastructure, and the extension of waterproof surfaces.

Another important prevention tool is the Document d'information communal sur les risques majeurs, or DICRIM, a short document designed to inform the local population in each municipality about existing risks and different ways to protect against them. Although the DICRIM is produced by municipalities and has no binding authority, it is an important illustration of good practice in flood risk management. In short, the mayor is charged with informing citizens if they are exposed to major risks, after which the government indicates protection measures and a municipality safety plan (Plan communal de sauvegarde, or PCS) designed to respond to a major disaster, should it occur. The Préfet des Alpes-Maritimes report (2016) analyzed 10 DICRIMs out of the 14 municipalities that suffered in the October 2015 PACA disaster (four did not have a DICRIM). In three of the DICRIMs, the mapping was inaccurate, with several locations missing from each map. The insurance data provided by the Caisse Centrale de Reassurance (CCR) show that, out of 85 municipalities in PACA, 10 did not have a DICRIM, another 13 had an old DICRIM (i.e., last updated before 2010), and 62 had a new one (updated since 2010). There is another dimension to this problem, suggesting that when local populations are aware of local flood risks, they have a greater tendency to ignore safety measures and so expose themselves to even greater risks (Ruin and Lutoff 2007).

2.3.2 Emergency management

During the October 2015 event, there was a lack of information on flood risk, a lack of preparedness to face catastrophic flooding, and no appropriate alert system in place. According to the Préfet des Alpes-Maritimes report (2016), the alert level, which is color-coded (yellow—low risk, orange—medium risk, and red—high risk), was misused. Météo-France has triggered orange alerts on a regular basis since the creation of the system, which has the effect of normalizing and trivializing the severity of the orange alert level. Furthermore, after observing the rainfall and discharge during the October 2015 event, the red alert signal should have been triggered. This was not the case, and the alert remained orange. Carrega (2016) highlights that inaccurate meteorological (rainfall) models forecasted only about 25% of the precipitation that occurred during the event, causing more confusion in the alert system. In addition, civilians apparently had insufficient knowledge of the alert protocol and poor understanding of the alert messages, with many confused about the color coding. The French alert system (Vigicrues) also came under criticism during the June 2010 Draguignan disaster, as it had not monitored the three main rivers that overflowed and caused damage to local communities (Sénat report 2012). Moreover, most hydrological stations located on the main rivers were destroyed by the flood, significantly limiting the capacity of researchers and decision makers to take precise discharge measurements (Payrastre et al. 2012). As Martin (2010) indicates, only three stations managed by the Direction régionale de l'Environnement, de l'Aménagement et du Logement (DREAL) were undamaged in the floods.

Another important aspect that needs to be investigated relates to the presence of emergency services. According to Sénat (2012), the Préfet des Alpes-Maritimes (2016) and the CEREMA (2019) reports, which examine the events presented in this paper (e.g., Draguignan June 2010, Côte d'Azur October 2015, PACA November–December 2019) noted that, despite the significant number of firefighters and emergency interventions involved (e.g., 600 firefighters and 1500 interventions in 2015), there was a lack of robust protocols for flood disasters. These numbers should be assessed with caution, since the insurance data we collected from the CCR show more than 3144 interventions in PACA, with Alpes-Maritimes accounting for around two-thirds (2,094) of all interventions. According to Sénat (2012), local populations, government, and emergency services downplay flood risk (considering it medium risk) compared to the risk of forest fire, which leads to municipal plans focusing on the risk of wildfire rather than flooding. Following the October 2015 event, the Ministry of Environment (Ministère de l'environnement, de l'énergie et de la mer) report (2016) suggested that a flood information and action week should be held, in which all stakeholders could be involved (e.g., Météo-France, government, fire-fighters) and where all past events could be discussed. This type of annual workshop already exists in areas prone to wildfire and earthquake in France, but not yet in areas prone to flooding.

2.3.3 Disaster recovery

Recovery in the French system is mainly based on insurance. Numerous authors have already pointed out some of the pitfalls of the current French flood insurance system and suggested a shift toward a public–private partnership (PPP) mechanism offering more flexibility (e.g., Fournier et al. 2018; Hudson et al. 2019; Barraqué and Moatty 2020). The French solidarity insurance system, although very inclusive, with a more than 95% penetration rate, seems unintentionally to have played a negative role in resilience by blocking the possibility of a BBB culture (Barraqué and Moatty 2020). In addition, according to Barraqué and Moatty (2020), the refunds received by disaster victims cover the actual damages incurred, but numerous other aspects, such as damage to outdoor housing or non-monetary impacts (e.g., emotional), are not taken into account. According to the Ministry of Environment report (2019), insurance companies refund on average €500 million for flood disasters every year, and the October 2015 event alone generated approximately €650 million damage, which represents a substantial financial blow to the insurance mechanism. A very high number of insurance claims (approximately 60,000) were registered, 60% relating to housing damage, 30% to cars, and 10% to business. The extended impacts of this event underlined the need for crisis units deployed in the field to deal directly with claims, as well as an increase in telephone assistance capacity and the acceleration of refunds from insurance companies.

Table 1 List of improvements of preventative measures put in place in affected areas after the October 2015 disaster

Structural measures	Several rehabilitation works around the area, including the creation of a hydraulic model and the stabilization of riversides Dam repairs: waterproofing renovated, cracking indicators installed, and damaged structures repaired Addition of flood defenses in several municipal buildings
Alert system	Improvement of the alert system, making it capable of receiving more than 1,400 emergency calls
Information, training and stakeholders	Distribution of 2,000 flyers in the riskiest areas of the municipality A yearly flood awareness day
Open tools and applications	Creation of a mobile App (#MyPredict) for the estimation of risk from weather forecasts and the management of flood warnings Purchase of 3D mapping tools and satellite phones by municipalities
General administrative measures	Removal of 50 tons of natural and anthropogenic waste from the valley and waterways and approximately 400,000 m^2 of riverbanks cleaned Revision of the PPRi, adding three hazard zones Creation of nine new PAPI projects

2.3.4 Persisting flood disasters after 2015

After the October 2015 Côte d'Azur disaster, a number of preventative measures were put in place by the government (Table 1).

Despite persistent government efforts, the impacts of flood events in the region do not appear to have lessened over time, and heavy rainfall events continue to cause loss of life and induce important material and immaterial damages. According to Météo-France,[2] 17 notable rainfall events took place in PACA between the October 2015 event and January 2020, leading to 14 flood deaths. Two recent events, November 22–24, 2019 and December 1, 2019, accounted for 11 of the victims and also caused serious material damage. According to the French Insurance Federation (Fédération Française d' Assurance, or FFA),[3] the costs of these two disasters total €390 million, while 57,000 insurance claims were registered (54% relating to damage to housing, 12% to cars, and 34% to businesses).

Similar scales of loss have been experienced in the Riou de l'Argentière drainage basin. The stream that burst its banks during the 2015 event did so again in 2019 causing damage to the same locations, while several protection dikes around the flooded area failed. This triggered protests from local inhabitants in Mandelieu-la-Napoule, as reported on France 3 news on December 1, 2019[4] and September 6, 2020.[5] In addition, the retention ponds promised after the 2015 disaster had still not been installed in several locations—they are

[2] http://pluiesextremes.meteo.fr/france-metropole/-Evenements-memorables-.html.

[3] https://www.ffa-assurance.fr.

[4] https://france3-regions.francetvinfo.fr/provence-alpes-cote-d-azur/intemperies-vaucluse-bouches-du-rhone-var-toujours-vigilance-orange-inondation-1756957.html.

[5] https://france3-regions.francetvinfo.fr/provence-alpes-cote-d-azur/alpes-maritimes/mandelieu-napoule-riou-peur-1869940.html.

now estimated to start functioning in 2023 (see France-Digues, December 9, 2019[6]). In 2018, Bokhove et al. (2019) conducted several workshops with local citizens at the River Brague in Biot, where residents asked for more flood retention measures. Furthermore, the CEREMA report (2019) illustrates that only 2% of the total population uses the #MyPredict app, which alerts people to flooding, underlining the need for better communication from those responsible for flood governance.

In October 2020, another flood event occurred. According to the FFA and CCR (2020) press releases, this event triggered 14,000 insurance claims with a total cost of €210 million. Again, most damage was done to housing (72%), followed by businesses (25%) and cars (3%); nine people died. These recurring disasters in the PACA region underline the need for new policies to be put in place. The Architectural Association of Côte d'Azur (Syndicat des architectes de la Côte d'Azur) suggested a new way of reducing flood risk, starting by adopting a BBB approach that strictly avoids the areas identified as potentially or previously flooded in the PPRi (Le Moniteur 2020).[7] Carrega and Michelot (2021) suggest that the PPRi of Saint-Martin-Vésubie offers exact mapping of floodplain limits and the two rivers (the Boréon and the Vésubie) that pass either side of the village. Nevertheless, it should be emphasized that in the village area the so-called danger zones sometimes extend beyond the floodplain and that the October 2020 floods overflowed from the floodplain in numerous locations, enlarging the main channel of the Vésubie. To examine the erosion processes in the drainage basin, which are important for anticipating future risks and taking preventative measures, we obtained six 3 m-resolution PlanetScope satellite scenes covering the Vésubie drainage basin. The images were atmospherically corrected and with no to low cloud (5 scenes 0% cloud, 1 scene 12% cloud). In Table 2, we provide the metadata for the six PlanetScope scenes.

Next, we calculated the normalized difference vegetation index (NDVI) for each pixel of the satellite scene as described in Eq. (1), where NIR is the near-infrared band and R is the red band in each satellite image.

$$\mathrm{NDVI} = \frac{(\mathrm{NIR} - R)}{(\mathrm{NIR} + R)} \tag{1}$$

We then created an NDVI difference map (using the NDVI imagery from before and after the event) to assess where storm-related changes took place (Fig. 3). The incidence angle, illumination azimuth angle, and spacecraft view angle between the two image sets have caused shadow effects leading to some false positives in the image (see Plekhov and Levine 2018, for similar issues). Nevertheless, the differences in the main channel of the Vésubie are clearly visible in the NDVI difference map.

[6] https://www.france-digues.fr/actualites/inondations-les-bassins-de-retention-font-debat/.

[7] https://www.lemoniteur.fr/article/il-est-evident-qu-il-ne-sera-pas-possible-de-reconstruire-a-l-identique-arnaud-reaux-croa-paca.2112289.

https://www.lemoniteur.fr/article/la-seule-solution-pour-faire-face-aux-phenomenes-extremes-est-de-ne-pas-etre-sur-le-chemin-de-l-eau-annick-mievre-agence-de-l-eau.2111219.

Table 2 PlanetScope scenes before and after the flood disaster of October 3, 2020, used for extracting NDVI difference

Company	Product	Resolution (m)	Scene ID	Date	Time (UTC)	Incidence Angle (°)	Cloud cover (%)
Planet Labs	Planet Scope	3	20200913_095313_24_1067	13-09-20	9:53:13	5.6	0
			20200913_095315_27_1067	13-09-20	9:53:15	5.6	0
			20200913_095317_30_1067	13-09-20	9:53:17	5.6	0
			20201010_094847_87_1065	10-10-20	9:48:47	1.1	12.31
			20201010_094849_97_1065	10-10-20	9:48:49	1.1	0
			20201010_094852_07_1065	10-10-20	9:48:52	1.1	0

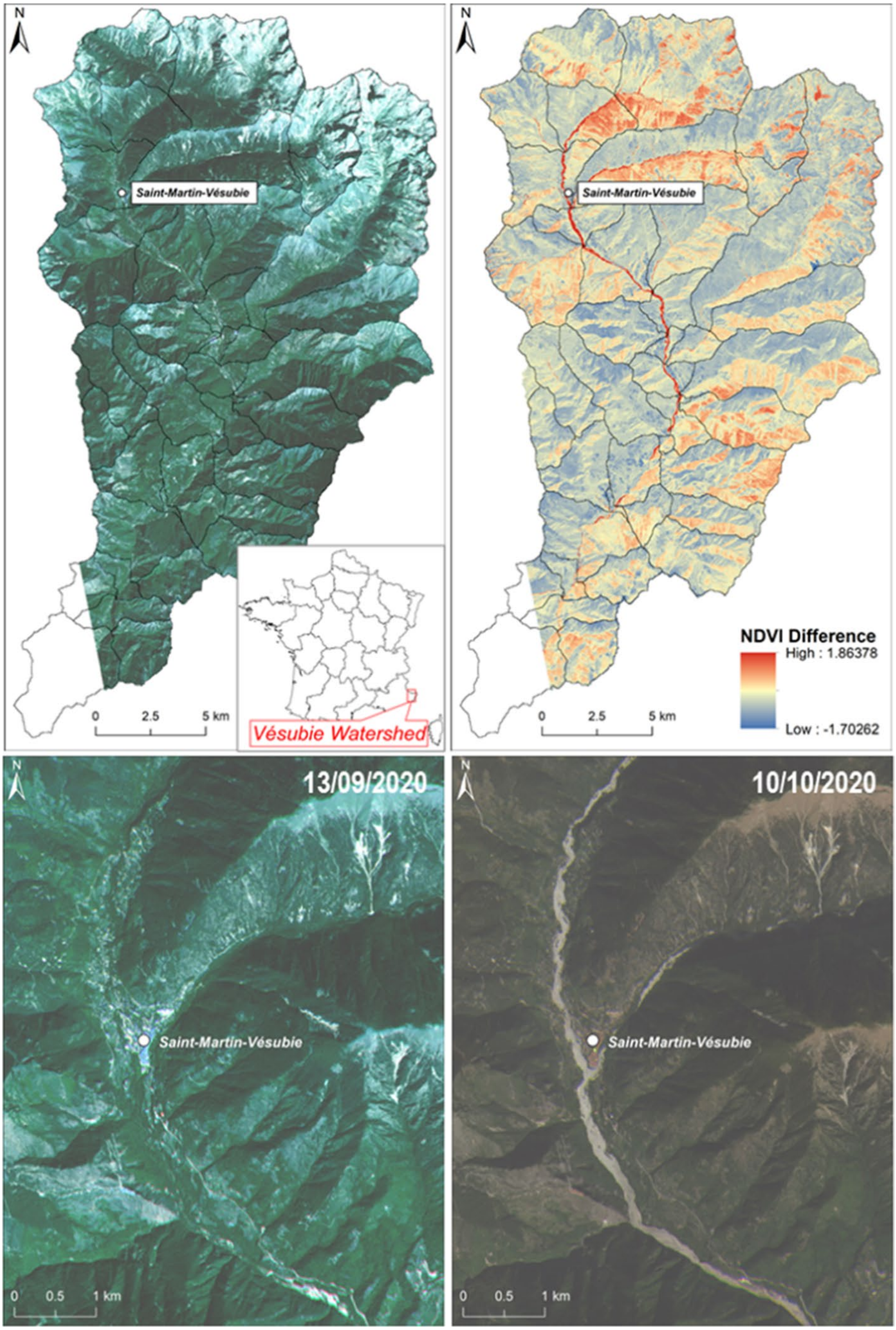

Fig. 3 Map of the erosion effects and extended flood limits of the event on October 3, 2020. **a** Location map, Vésubie drainage basin; **b** NDVI difference map—the higher the difference in NDVI, the greater the impact of the flood. Very high values appear in the Vésubie channel; **c** The village of Saint-Martin-Vésubie before the event September 13, 2020; **d** The village of Saint-Martin-Vésubie after the event, October 10, 2020—notice significant excess sedimentation in the main channel of the Vésubie

INTERNAL FACTORS	
STRENGTHS (+)	**WEAKNESSES (–)**
• S1. Important number of robust risk prevention mechanisms (e.g. PPRi, PAPI) • S2. Very high insurance penetration rate (approximately 100%) • S3. Significant know-how of the prevention specialists (e.g. mapping, technical and engineering services) • S4. Well defined flood management scale (i.e. drainage basin) • S5. Participation in regulatory protocols from an important number of government services	• W1. Due to their important number risk prevention tools are, in some cases, not updated regularly • W2.1. Insurance funding reconstruction of damaged elements in same locations instead of using a Build Back Better logic • W2.2. Risk is only based on declared damages thereby limiting the capacity for risk reduction • W3.1. Lack of synergy between the three main elements of the cycle (Figure 1 A, B, C) • W3.2. Lack of communication between different steps of each element (prepare, control, organise etc.) • W4.1. Drainage basin scale not easily understood by non experts • W4.2. Drainage basin scale giving a false idea that risk is limited on flood hazard areas • W5. Lack of participation from local population

EXTERNAL FACTORS	
OPPORTUNITIES (+)	**THREATS (–)**
• O1. Prevention mechanism easily evaluated due to the existence of long-term data • O2.1. Government reforms to recentralize accounting and financial management • O2.2. Increase of funding for flood insurance • O3.1. Flood Risk Governance issues clearly reported in official government aftermath of events documents • O3.2. Acknowledgement of fragmentation and lack of synergy issues in the flood governance system from the government • O4. Capacity to monitor the effect of prevention approaches in the regional and municipal scale • O5.1. Important number of research programs focusing on flood risk governance, flood hazard, flood modelling etc. • O5.2. Application of corrective measures (See Table 1 - List of improvements after October 2015)	• T1.1. Increasing urban concentration • T1.2. Impact of climate change on flood frequency and severity • T2. Repetitive flood damage due to climate change could cause insurance cancellation • T3. Decreasing public subsidies causing issues in flood risk prevention • T4. Decentralization causing public funding disparities • T5. Gap between specialists' idea of a major risk and the perception of risk from the public

Fig. 4 SWOT analysis of the French FRG

3 Lessons for French flood risk governance: a SWOT analysis

In this study, we illustrate, through an analysis of flood disasters in the PACA region, that the extent of flood damage and disaster insurance claims in PACA have not decreased over time. Furthermore, flood risk culture seems to be addressed at the individual rather than the collective (municipal) level. Finally, there has been no significant investment in vulnerability reduction and resilience building (e.g., BBB programs, managed retreat). Building on this case study, it is timely to analyze the main strengths, weaknesses, opportunities, and threats that concern the French FRG system (Fig. 4) to identify any shortcomings and suggest future improvements. To do this, we follow the approach used in past research (e.g., the European STAR-FLOOD project), which provided SWOT analysis for individual national FRG systems, such as the UK and Belgium (e.g., Alexander et al. 2016; Mees et al. 2016).

The first strength observed in the French system is the existence of an important number of prevention mechanisms and legal tools, such as the PPRi and the PAPI, discussed in Sect. 2. This legal robustness is further underlined by constitutional principles of national solidarity to cope with disasters, and the image of the central state as the guardian of public safety, which is largely shared by the public (Fournier et al. 2018). For example, the hazard and vulnerability mapping provided by the PPRi is an important tool for decision makers and is easily accessible by the public through mobile applications, etc. In addition, the combination of PPRi mapping and detailed information about damage provided in post-event reports can provide useful material for evaluating the efficiency of the PPRi and PAPI. On the other hand, these well-defined prevention mechanisms have a drawback, since they need constant updating, which in some cases is not done on time due to lack of funds or personnel (e.g., after the 2015 disaster in Cannes it was found that the most recent PPRi had been approved in 2003). For example, a significant number of French pensioners choose to purchase housing and spend their retirement time in PACA with no previous knowledge of flood risk; they are therefore likely to be unaware of the likelihood that their house is in a high flood hazard zone. To optimize these prevention mechanisms in the future, decision makers will have to take into account the increasing concentration in urban centers as well as the impacts of climate change on hazard behavior (e.g., flood frequency and severity). As Dubert et al. (2016) explain, most exposed municipalities and municipalities with a high number of fatalities all have approved PPRis. Nevertheless, some highly exposed municipalities have an outdated PPRi (older than four years at the time of an event) or no PPRi at all. This also occurs in other regions of France, as Douvinet et al. (2011) illustrate with their example of La-Faute-sur-Mer, where 100 houses were built after 2000 and were flooded in 2010. The PPRi for La-Faute-sur-Mer, showing that the houses were built in a high-risk area, only received final approval in 2007. Furthermore, during the June 2010 Draguignan disaster, 22% of residential buildings were located in a flood risk zone and approximately one in three employees were commuting into the flood risk zone for their work, increasing the economic cost of the disaster (INSEE 2018). Guillier et al. (2016) recommend the inclusion of the PAPI in the governance framework, since it is currently missing from around 50% of high flood risk areas (Territoires à risque important d'inondation, or TRI): they believe that this absence could be due to the lack of robust government services at a local level or the non-prioritization of flood risk in the development of these areas.

The second strength of the French FRG is the significant insurance penetration rate (approximately 95%) due to a direct purchase requirement. This can be considered as welfare-enhancing, as it improves financial coverage against disasters (e.g., Hudson et al. 2019). Furthermore, the Ministry of Ecological Transition report (2020) announced that the role of the state in the CatNat insurance scheme will be reinforced by recentralizing financial activities which will add support to the management of these funds from the public reinsurer, the Caisse Centrale de Réassurance. The report also underlines that complementary funding will be provided to tackle flooding (after the repeated disasters in PACA in the previous 10 years). Despite these important developments, the French solidarity insurance scheme seems to suffer from several weaknesses. First, the current market structure could be unsuitable for coping with future increases in flood risk due to insufficient incentives for risk reduction. By funding properties and locations that are damaged repeatedly by flooding, insurance is incompatible with a BBB logic, limiting the capacity for resilience. As the EU Floods Directive (2007) suggests, reducing flood risk by reducing hazard, vulnerability, and exposure must be the objective. According to Kron et al. (2019), if insurance receives the residual risk, which is difficult to control through structural and non-structural measures, it can play the role of a lever for policy improvement. Second, in some cases victims of a severe climate-related disaster do not even know if they are covered by the CatNat system. This has been the case for agricultural producers experiencing heavy hailstorms, which are not covered by CatNat.[8] In France, there is no empirical information on voluntary flood insurance purchases since the French solidarity framework is compulsory, while risk estimation seems to be based only on declared damages, limiting the capacity for risk reduction. It is now feared that repeated flood disasters due to climate change could lead to the dissolution of flood insurance, which is the main threat for the future if the framework remains stagnant (Lamond and Penning-Rowsell 2014). As Douvinet and Vinet (2012) indicate, a major disaster (costing more than €10 billion) would make the CatNat system move toward increasing premiums or deductibles by all possible means. A third weakness of widespread insurance for well-delimited flood hazards is that it generates moral hazard—that is, the incentive to increase exposure to risk because the individual will not bear the full cost of that risk (e.g., Lamond and Penning-Rowsell 2014). This is not the case for other natural hazards, like earthquake, where location predictions are less straightforward (Nguyen and Noy 2019). Past research points to a more flexible system with increased PPP (keeping penetration rates as high as possible) and more funding for reducing vulnerability and improving resilience through BBB (e.g., Fournier et al 2018; Hudson et al. 2019; Kron et al. 2019).

The third strength of the system is the high expertise and know-how of public services. France has a long tradition of hazard and vulnerability mapping as well as expert government engineering services (Larrue et al. 2016; Fournier et al. 2018). The country has a transparent system in that issues are clearly reported in government documents in post-event reports (e.g., the Préfet des Alpes-Maritimes report 2016), which are concise and distributed in the public domain. Nevertheless, this high degree of specialization is counter-balanced by a lack of synergy between actors and stakeholders in the three main phases of the FRG cycle (risk prevention, emergency management, and disaster recovery—see Fig. 1). As an example, there is an observable a lack of appropriate training and information for response teams on the ground and emergency services, such as firefighters, are obliged to rely on the protocols for other natural disasters (e.g., forest fires or earthquakes). Moreover, there is a lack of communication between actors in the different steps (preparation, control, organization, etc.) of the three main phases of the cycle (risk prevention, emergency management, and disaster recovery). For example, we see a failure of communication between meteorological (rainfall) model specialists and alert system experts (Carrega 2016) in numerous examples described in Sect. 2.3 Poor communication has played a significant role globally in past major disasters. Cyranoski (2011) observed that during the 2011 Fukushima disaster in Japan a warning system based on initial seismic signal predicted a limited region of intense shaking. As a result, the risk of tsunami was heavily underestimated, and local people and emergency services did not respond at maximum alert. The actual shaking was far more severe and widespread.

[8] https://www.publicsenat.fr/article/parlementaire/catastrophes-naturelles-le-senat-veut-reformer-le-systeme-d-indemnisation.

The fourth strength of the French FRG is the well-defined spatial scale (i.e., drainage basin) at which flood risk management is undertaken. This was implemented for the first time after 2007 to transpose the EU Floods Directive into French law (Larrue et al. 2016). The study of flood risk in drainage basins brings some important benefits, especially for the analysis of flood hazard, since the rapid accumulation of runoff (following heavy storms) can be controlled upstream from the catchment area (e.g., riparian zone management). In addition, wetland areas within the basin can be studied and preserved as non-structural anti-flooding measures. With this in mind, river contracts were created. These bring together various partners (the Préfet of the department, water agencies, and other local authorities) focusing on a set of common goals ranging from management of water quality, enhancement of the aquatic environment and water resources, to defense against flooding. The PAPI are also designed on a drainage basin scale and must combine measures and suggestions for improving knowledge, monitoring and forecasting, information, planning, protection works, reduction of vulnerability (of buildings), crisis management preparedness, and feedback on operations (Larrue et al. 2016). Studying floods on a drainage basin scale presents opportunities for the French FRG, including the potential to monitor the effects of existing prevention approaches at a regional or municipal scale. Nevertheless, the drainage basin scale also has weaknesses. First, it is not easily understood by non-experts and second, it provides a false perception that risk is limited to flood hazard areas. This limits the capacity to reduce vulnerability in areas that could suffer indirectly from flooding issues, for example, a municipality outside the flooding zone, many of whose residents could work in flood-prone areas and would suffer indirect economic impacts. Since 1982, a decentralization process has led to the transfer of responsibilities from central government toward local authorities (Kaufmann and Wiering 2017), with the aim of creating command and response units for flood disasters at a local level and adapted to different types of flooding (e.g., Mediterranean flash floods, fluvial floods in northern France). This decentralization can create important disparities in public funding between municipalities. For example, despite repeated flooding (2015, 2019, 2020) in the Riou de l'Argentière drainage basin, the local government has not focused on improving resilience or allocated any funding to the relocation of constantly damaged elements. In contrast, as Heinzlef et al. (2019) indicate, the city authorities in Avignon have demanded increased resilience planning for frequently flooded areas and placed the city under a pilot study. Arnaud-Fassetta et al. (2009) emphasize that, for every drainage basin, flood-intense periods over past centuries and their characteristics must be studied and compared to recent decades to observe abnormalities and explanations for current disasters. Nevertheless, this does not always happen, leading to myopic assessments that focus only on recent flooding (over the past 30 years).

The fifth strength that we identified in the French FRG system is that a significant number of government services participate in shaping flood governance protocols. As Kaufmann and Wiering (2017) explain, managing flood risk is conceived as a collective task. Fournier et al. (2018) illustrate the numerous instruments and institutions that participate in tackling flooding in the country (e.g., CEREMA, DREAL, local prefecture experts, ministries), meaning that a large number of specialists are focused on preventing flood disasters and alerting local populations. This is also evident in the large number of research programs and amount of funding directed toward flood governance, flood hazard, and risk modelling (e.g., Boudou et al. 2016; Montané et al. 2017; Liefferink et al. 2018). Other possibilities for the participation of government services in flood governance protocols are the application of corrective measures (see Table 1, after the October 2015 disaster in PACA) and the desire to improve the system, evident in the transparent official post-event reports available in the public domain (e.g., Préfet of Alpes-Maritimes report 2016). Nevertheless, due to a "state covers all" logic, participation from local populations is minimal, which does not help to improve resilience. For example, only one flood awareness day per year was planned in PACA after the October 2015 disaster. Ideally, region-wide workshops considering all three phases of the cycle (risk prevention, emergency management, and disaster recovery) should be held, and explanatory flyers should be tailored to the needs of each municipality. These would help shape the local population's perception of risk, poor understanding of which is another threat to the French FRG system. It seems that institutions and government do not always encourage citizens to participate in decision-making processes, while support for individual measures that would increase resilience is still lacking (Moatty et al. 2018). According to the IRSN (2020), despite the alarming impacts of climate change on flood frequency and severity, the French population's perception of flood risk has not changed much since 1997. Around 40% consider the risk to be high, 40% consider it to be medium, and 20% consider it to be low. In addition, even though flooding is by far the costliest natural disaster in France, the population feels confident that state services provide greater protection from flooding than from other risks, like pesticides, terrorism, or environmental pollution. Local social services should participate in the framework by conducting vulnerability analyses for criteria that have played a crucial role in past disasters. For example, during the Var flash floods in 2011, seven of the 13 victims who died in their own home were aged over 80, indicating that the age criterion should be considered for future studies (Vinet et al. 2012). Sassi (2011) provided a monetary evaluation of damages induced by a December 2003 flood event in PACA. Apart from this attempt, to our knowledge no other modelling studies evaluate the economic impacts of flood events in the area. We assume that insurance companies could have more knowledge about this issue, but the fact that their data are confidential does not help to improve the current FRG framework. This is why increasing PPP, as suggested in previous research (e.g., Fournier et al. 2018; Hudson et al. 2019; Kron et al. 2019), might be mutually beneficial.

4 Conclusion

In this study, we perform an in-depth analysis of the French FRG framework (Fig. 1) using multiple sources (insurance datasets, scientific articles, satellite data, and grey literature) to (1) analyze modern flood disasters in the PACA region; (2) discuss the efficiency of French public policy instruments; (3) perform a SWOT analysis of the French FRG; and (4) suggest improvements. Our analysis shows that despite the application of costly new structural and non-structural measures from the government (following the October 2015 disaster), the impacts of flood events in the region do not appear to have lessened over time and consecutive events have led to 23 more flood fatalities. Since flood hazard is predicted to intensify, due to climate change, the situation demands improvements in the French FRG approach to avoid further major disasters. The key findings of this paper illustrate that, despite its numerous strengths, the French FRG could benefit from several improvements. These include: (1) regular updates of risk prevention plans and tools (e.g., PPRI, PAPI); (2) the adoption of a BBB logic rather than repairing damage in the same locations; (3) taking undeclared damages into account in flood risk models (not just those declared to flood insurance); (4) increased communication between actors at all the different steps in each cycle (preparation, control, organization, etc.); (5) increased communication between the three main phases of the cycle (risk prevention, emergency management, disaster recovery); (6) an approach that extends the risk analysis outside the borders of the drainage basin (to be used in combination with current basin risk models); and (7) increased participation in FRG by the local population.

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Declarations

Conflict of interest The authors declare that there is no conflict of interest.

References

Aerts JCJH, Botzen WJ, Clarke KC et al (2018) Integrating human behaviour dynamics into flood disaster risk assessment. Nat Clim Chang 8:193–199. https://doi.org/10.1038/s41558-018-0085-1

Alexander M, Priest S, Mees H (2016) A framework for evaluating flood risk governance. Environ Sci Policy 64:38–47. https://doi.org/10.1016/j.envsci.2016.06.004

Arnaud-Fassetta G, Astrade L, Bardou E et al (2009) Géomorphologie fluviale et gestion des risques fluviaux. Geomorphol Reli Process Environ 15:109–128. https://doi.org/10.4000/geomorphologie.7554

ARTELIA (2017) Étude de la problématique inondation des vallons des Combes et de Sainte-Colombe : diagnostic des réseaux pluviaux et propositions d'aménagement. Métropole Nice Cote d'Azur, Direction de l'Eau, de l'Air et de la Qualité des Milieux, Service Assainissement - Pôle Hydraulique et Pluvial. https://www.alpes-maritimes.gouv.fr/content/download/31411/247873/file/6.Rapport_Combes_VF.pdf

Assemblée Nationale (2001) Rapport fait au nom de la commission d'enquête sur les causes des inondations répétitives ou exceptionnelles et sur les conséquences des intempéries afin d'établir les responsabilités, d'évaluer les coûts ainsi que la pertinence des outils de prévention, d'alerte et d'indemnisation. http://www.assemblee-nationale.fr/rap-enq/r3386-01.asp

Ballais J, Ségura P (1995) La catastrophe de Vaison- la-Romaine (22 septembre 1992) : une inondation dans un géosystème anthropisé. In: 120ème Congrès national des Sociétés historiques et scientifiques. 1–48.

Barraqué B, Moatty A (2020) The French Cat' Nat' system: post-flood recovery and resilience issues. Environ Hazards 19:285–300. https://doi.org/10.1080/17477891.2019.1696738
Bokhove O, Kelmanson MA, Kent T et al (2019) Communicating (nature-based) flood-mitigation schemes using flood-excess volume. River Res Appl 35:1402–1414. https://doi.org/10.1002/rra.3507
Boudou M, Lang M, Vinet F, Cœur D (2016) Comparative hazard analysis of processes leading to remarkable flash floods (France, 1930–1999). J Hydrol 541:533–552. https://doi.org/10.1016/j.jhydrol.2016.05.032
Bouwer LM (2011) Have disaster losses increased due to anthropogenic climate change? Bull Am Meteorol Soc 92:39–46. https://doi.org/10.1175/2010BAMS3092.1
Carrega P (2016) Les inondations azuréennes du 3 octobre 2015: un lourd bilan lié à un risque composite. Pollut Atmosphérique 1–26. https://doi.org/10.4267/pollution-atmospherique.5475
Carrega P, Michelot N (2021) Une catastrophe hors norme d'origine météorologique le 2 octobre 2020 dans les montagnes des Alpes-Maritimes. Physio-Géol 16:1–70
CEREMA (2019) Perception du risque inondation, Analyse d'expériences et recommandations pour mener une enquête auprès des populations. http://www.paca.developpement-durable.gouv.fr/IMG/pdf/rapport_enquete_perception_risque_inondation_arc_med.pdf
Coumou D, Rahmstorf S (2012) A decade of weather extremes. Nat Clim Chang 2:491–496. https://doi.org/10.1038/nclimate1452
Creach A, Bastidas-Arteaga E, Pardo S, Mercier D (2020) Vulnerability and costs of adaptation strategies for housing subjected to flood risks: Application to La Guérinière France. Mar Policy 117:103438. https://doi.org/10.1016/j.marpol.2019.02.010
CRED-UNISDR (2015) The Human Cost of Weather Related Disasters, 1995–2015. Centre for Research on the Epidemiology of Disasters and United Nations Office for Disaster Risk Reduction.
Cremades R, Surminski S, Máñez Costa M et al (2018) Using the adaptive cycle in climate-risk insurance to design resilient futures. Nat Clim Chang 8:4–7. https://doi.org/10.1038/s41558-017-0044-2
Crichton D (2008) Role of insurance in reducing flood risk. Geneva Pap Risk Insur Issues Pract 33:117–132. https://doi.org/10.1057/palgrave.gpp.2510151
Cyranoski D (2011) Japan faces up to failure of its earthquake preparations. Nature 471:556–557. https://doi.org/10.1038/471556a
Dixit A (2003) Floods and vulnerability: need to rethink flood management. Nat Hazards 28:155–179. https://doi.org/10.1023/A:1021134218121
Douvinet J, Defossez S, Anselle A, Denolle A-S (2011) Les maires face aux plans de prévention du risque inondation (Ppri). Espac Géographique 40:31. https://doi.org/10.3917/eg.401.0031
Douvinet J, Vinet F (2012) La carte des arrêtés «CatNat» pour les inondations: analyse spatio-temporelle. Mappemonde 107:1–13
Dubert G, Guillier F, Nussbaum R, et al (2016) L'analyse de la vulnérabilité aux inondations en région PACA: l'apport des observatoires. La Houille Blanche 2016-June: 18–21. https://doi.org/10.1051/lhb/2016025
EU, (2007) Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks. Off J Eur Union L288:27–34
Evin G, Wilhelm B, Jenny JP (2019) Flood hazard assessment of the Rhône River revisited with reconstructed discharges from lake sediments. Glob Planet Change 172:114–123. https://doi.org/10.1016/j.gloplacha.2018.09.010
Fournier M, Larrue C, Schellenberger T (2018) Changes in flood risk governance in France: a David and Goliath story? J Flood Risk Manag 11:261–270. https://doi.org/10.1111/jfr3.12314
Fournier M (2020) Flood governance in France: from hegemony to diversity in the French flood-risk management actors' network. In: La Jeunesse I, Larrue C (eds) Facing hydrometeorological extreme events: a governance issue, First edn. Wiley, London, pp 125–139
FFA and CCR (2020) Inondations dans les Alpes-Maritimes 14000 sinistres estimés pour un coût évalué à 210 millions d'euros. https://catastrophes-naturelles.ccr.fr/-/inondations-dans-les-alpes-maritimes
Guillier F (2017) French insurance and flood risk: assessing the impact of prevention through the rating of action programs for flood prevention. Int J Disaster Risk Sci 8:284–295. https://doi.org/10.1007/s13753-017-0140-y
Guillier F, Larrue C, Nussbaum R (2016) Les PAPI: Quelle efficacité d'un dispositif fédérateur pour la réduction de la vulnérabilité collective aux inondations ? La Houille Blanche 2016-Janua: 12–18. https://doi.org/10.1051/lhb/2016012
Hall JW, Sayers PB, Dawson RJ (2005) National-scale assessment of current and future flood risk in England and Wales. Nat Hazards 36:147–164. https://doi.org/10.1007/s11069-004-4546-7
Hallegatte S, Green C, Nicholls RJ, Corfee-Morlot J (2013) Future flood losses in major coastal cities. Nat Clim Chang 3:802–806. https://doi.org/10.1038/nclimate1979

Heinzlef C, Becue V, Serre D (2019) Operationalizing urban resilience to floods in embanked territories: application in Avignon, Provence Alpes Côte d'azur region. Saf Sci 118:181–193. https://doi.org/10.1016/j.ssci.2019.05.003

Hudson P, Botzen WJW, Aerts JCJH (2019) Flood insurance arrangements in the European Union for future flood risk under climate and socioeconomic change. Glob Environ Chang 58:101966. https://doi.org/10.1016/j.gloenvcha.2019.101966

INSEE (2018) Un million d'habitants vivent en zone inondable. https://www.insee.fr/fr/statistiques/3614748#consulter

IRGC (2020) Involving stakholders in the risk governance process. Lausanne: EPFL International Risk Governance Center.

IRSN (2020) Baromètre 2020 : La perception des risques et de la sécurité par les français. https://www.irsn.fr/FR/IRSN/Publications/barometre/Documents/IRSN_Barometre_2020-graphiques.pdf

Ishiwatari M (2019) Flood risk governance: Establishing collaborative mechanism for integrated approach. Prog Disaster Sci 2:100014. https://doi.org/10.1016/j.pdisas.2019.100014

Jongman B (2018) Effective adaptation to rising flood risk. Nat Commun 9:9–11. https://doi.org/10.1038/s41467-018-04396-1

Kaufmann M, Wiering M (2017) Discursive junctions in flood risk governance: a comparative understanding in six European countries. J Environ Manage 196:376–386. https://doi.org/10.1016/j.jenvman.2017.03.012

Koc K, Işık Z (2020) A multi-agent-based model for sustainable governance of urban flood risk mitigation measures. Nat Hazards 104:1079–1110. https://doi.org/10.1007/s11069-020-04205-3

Kron W, Eichner J, Kundzewicz ZW (2019) Reduction of flood risk in Europe: reflections from a reinsurance perspective. J Hydrol 576:197–209. https://doi.org/10.1016/j.jhydrol.2019.06.050

Lamond JE, Bhattacharya-Mis N, Chan FKS et al (2019) Flood risk insurance, mitigation and commercial property valuation. Prop Manag 37:512–528. https://doi.org/10.1108/PM-11-2018-0058

Lamond J, Penning-Rowsell E (2014) The robustness of flood insurance regimes given changing risk resulting from climate change. Clim Risk Manag 2:1–10. https://doi.org/10.1016/j.crm.2014.03.001

Larrue C, Bruzzone S, Lévy L, et al (2016) Analysing and evaluating flood risk governance in France. From state policy to local strategies

Le Coz J, Patalano A, Collins D et al (2016) Crowdsourced data for flood hydrology: feedback from recent citizen science projects in Argentina, France and New Zealand. J Hydrol 541:766–777. https://doi.org/10.1016/j.jhydrol.2016.07.036

Lenderink G, Van Meijgaard E (2008) Increase in hourly precipitation extremes beyond expectations from temperature changes. Nat Geosci 1:511–514. https://doi.org/10.1038/ngeo262

Liefferink D, Wiering M, Crabbé A, Hegger D (2018) Explaining stability and change. Comparing flood risk governance in Belgium, France, the Netherlands, and Poland. J Flood Risk Manag 11:281–290. https://doi.org/10.1111/jfr3.12325

Luke A, Sanders BF, Goodrich KA et al (2018) Going beyond the flood insurance rate map: insights from flood hazard map co-production. Nat Hazards Earth Syst Sci 18:1097–1120. https://doi.org/10.5194/nhess-18-1097-2018

Lumbroso D, Stone K, Vinet F (2011) An assessment of flood emergency plans in England and Wales, France and the Netherlands. Nat Hazards 58:341–363. https://doi.org/10.1007/s11069-010-9671-x

Magnan S (1995) Catastrophe insurance system in France. Geneva Pap Risk Insur - Issues Pract 20:474–480. https://doi.org/10.1057/gpp.1995.42

Martin C (2010) Les inondations du 15 juin 2010 dans le Centre Var: réflexion sur un épisode exceptionnel. Etudes Géographie Phys 2010:41–76

Mees H, Suykens C, Beyers J-C, et al (2016) Analysing and evaluating flood risk governance in Belgium. Dealing with flood risks in an urbanised and institutionally complex country.

Miller JD, Hutchins M (2017) The impacts of urbanisation and climate change on urban flooding and urban water quality: a review of the evidence concerning the United Kingdom. J Hydrol Reg Stud 12:345–362. https://doi.org/10.1016/j.ejrh.2017.06.006

Ministère de la transition écologique (2020) Prévention des inondations. https://www.ecologie.gouv.fr/prevention-des-inondations

Ministère de la transition écologique (2019) Guide méthodologique "APRÈS inondation" Organisation de la collecte des données issues des REX inondation. Proposé par le rapport n° 012486-01. «Organisation de la collecte des données issues des REX inondations». https://www.cerema.fr/system/files/documents/2019/09/012486-01_guide-methodologique_cle7b1338.pdf

Ministère de l'environnement, de l'énergie et de la mer (2016) Propositions d'actions pour mieux gérer les inondations en zone méditerranéenne et limiter leurs conséquences. Propositions d'actions pour

mieux gérer les inondations en zone méditerranéenne et limiter leurs conséquences. Rapport n° 010664-01. https://www.vie-publique.fr/sites/default/files/rapport/pdf/174000015.pdf
Moatty A, Vinet F, Defossez S et al (2018) Intégrer une «éthique préventive» dans le processus de relèvement post-catastrophe : résilience, adaptation et «reconstruction préventive». La Houille Blanche 5–6:11–19
Montané A, Buffin-Bélanger T, Vinet F, Vento O (2017) Mappings extreme floods with numerical floodplain models (NFM) in France. Appl Geogr 80:15–22. https://doi.org/10.1016/j.apgeog.2017.01.002
NatCatSERVICE (2017) Data on natural disasters since 1980. Munich Re. https://www.munichre.com/en/solutions/for-industry-clients/natcatservice.html
Nguyen CN, Noy I (2020) Comparing earthquake insurance programmes: how would Japan and California have fared after the 2010–11 earthquakes in New Zealand? Disasters 44:367–389. https://doi.org/10.1111/disa.12371
Noy I, Ferrarini B, Park D (2019) Build back better adb economics. Asian Dev Bank Econ Work Pap Ser
Paprotny D, Sebastian A, Morales-Nápoles O, Jonkman SN (2018) Trends in flood losses in Europe over the past 150 years. Nat Commun 9. https://doi.org/10.1038/s41467-018-04253-1
Payrastre O, Gaume E, Javelle P, et al (2012) Analyse hydrologique de la crue-éclair catastrophique du 15 juin 2010 dans la région de Draguignan (VAR, France). In: Evénements extrêmes fluviaux et maritimes. Leurs variabilités spatiales et chronologiques dans l'ouest de l'Europe. 34èmes journées de l'hydraulique. pp 1–8
Petrucci O, Aceto L, Bianchi C et al (2019) Flood fatalities in Europe, 1980–2018: variability, features, and lessons to learn. Water 11:28. https://doi.org/10.3390/w11081682
Plekhov D, Levine EI (2018) Assessing the effects of severe weather events through remote sensing on Samothrace, Greece: applications for the management of cultural resources. J Archaeol Sci Reports 21:810–820. https://doi.org/10.1016/j.jasrep.2018.09.002
Préfet des Alpes-Maritimes report (2016) Inondations des 3 et 4 octobre 2015 dans les Alpes-Maritimes : retour d'expérience.
Roudier P, Andersson JCM, Donnelly C et al (2016) Projections of future floods and hydrological droughts in Europe under a +2°C global warming. Clim Change 135:341–355. https://doi.org/10.1007/s10584-015-1570-4
Ruin I, Lutoff C (2004) Vulnérabilité face aux crues rapides et mobilités des populations en temps de crise. La Houille Blanche 6:114–119. https://doi.org/10.1051/lhb
Sassi M (2011) A monetary evaluation of damages induced by natural flood risk in PACA region: an applied general equilibrium analysis. Rev d'Économie Régionale Urbaine 627–650
Scolobig A, Komendantova N, Patt A et al (2014) Multi-risk governance for natural hazards in Naples and Guadeloupe. Nat Hazards 73:1523–1545. https://doi.org/10.1007/s11069-014-1152-1
Sénat (2012) Rapport d´information fait au nom de la mission commune d'information sur les inondations qui se sont produites dans le var, et plus largement, dans le sud-est de la France au mois de novembre 2011. Session extraordinaire de 2011–2012. N° 775. https://www.senat.fr/rap/r11-775/r11-7751.pdf
Singkran N, Kandasamy J (2016) Developing a strategic flood risk management framework for Bangkok, Thailand. Nat Hazards 84:933–957. https://doi.org/10.1007/s11069-016-2467-x
Surminski S, Aerts JCJH, Botzen WJW et al (2015) Reflections on the current debate on how to link flood insurance and disaster risk reduction in the European Union. Nat Hazards 79:1451–1479. https://doi.org/10.1007/s11069-015-1832-5
Swiss Re (2014) Mind the risk: a global ranking of cities under threat from natural disasters.
Tullos D, Byron E, Galloway G et al (2016) Review of challenges of and practices for sustainable management of mountain flood hazards. Nat Hazards 83:1763–1797. https://doi.org/10.1007/s11069-016-2400-3
UNISDR (United Nations International Strategy for Disaster Reduction) (2009) Terminology on Disaster Risk Reduction.
UNISDR (United Nations International Strategy for Disaster Reduction) (2015) Sendai framework for disaster risk reduction 2015–2030. http://www.wcdrr.org/uploads/Sendai_Framework_for_Disaster_Risk_Reduction_2015-2030.pdf.
Vedeld T, Coly A, Ndour NM, Hellevik S (2016) Climate adaptation at what scale? Multi-level governance, resilience, and coproduction in Saint Louis, Senegal. Nat Hazards 82:173–199. https://doi.org/10.1007/s11069-015-1875-7
Vinet F (2004) Hydrologie urbaine. La. Houille Blanche 6:76–82. https://doi.org/10.1051/lhb
Vinet F (2007) Flood risk management in French Mediterranean basins. WIT Trans Ecol Environ 104:261–270. https://doi.org/10.2495/RM070251

Vinet F (2008a) From hazard reduction to integrated risk management: toward adaptive flood prevention in Europe. WIT Trans Ecol Environ 118:113–122. https://doi.org/10.2495/FRIAR080111

Vinet F (2008b) Geographical analysis of damage due to flash floods in southern France: the cases of 12–13 November 1999 and 8–9 September 2002. Appl Geogr 28:323–336. https://doi.org/10.1016/j.apgeog.2008.02.007

Vinet F, Lumbroso D, Defossez S, Boissier L (2012) A comparative analysis of the loss of life during two recent floods in France: the sea surge caused by the storm Xynthia and the flash flood in Var. Nat Hazards 61:1179–1201. https://doi.org/10.1007/s11069-011-9975-5

Winsemius HC, Aerts JCJH, Van Beek LPH et al (2016) Global drivers of future river flood risk. Nat Clim Chang 6:381–385. https://doi.org/10.1038/nclimate2893

Zhang W, Villarini G, Vecchi GA, Smith JA (2018) Urbanization exacerbated the rainfall and flooding caused by hurricane Harvey in Houston. Nature 563:384–388. https://doi.org/10.1038/s41586-018-0676-z